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AFGL-TR-89-0088

AFGL BALLOON TELEMETRY FACILITY

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Scientific Report No. 1

15 August 1986

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFGL-TR-89-0088	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AFGL Balloon Telemetry Facility		5. TYPE OF REPORT & PERIOD COVERED Scientific Report #1
		6. PERFORMING ORG. REPORT NUMBER PR01136
7. AUTHOR(s) Victor R. Parkerson		8. CONTRACT OR GRANT NUMBER(s) F19628-84-C-0039
9. PERFORMING ORGANIZATION NAME AND ADDRESS Physical Science Laboratory P.O. Box Las Cruces, NM 88003		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 765912AE
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Monitor: Ted Mansfield/LC		12. REPORT DATE 15 August 1986
		13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

AFGL DETACHMENT 1 Balloon Flight Facility, Holloman AFB, NM
PDP-11/40 Digital Computer
EMR telemetry equipment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report discusses the capabilities available at AFGL Detachment 1 for reception, collection, manipulation, recording, and display of telemetry data transmitted from balloon-borne instrumentation.

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1. INTRODUCTION

This report describes the data acquisition and display capability available to scientific experimenters for developmental projects utilizing a balloon vehicle from the Air Force Geophysics Laboratory (AFGL), Detachment 1, Holloman AFB, New Mexico.

The average experimenter or "user" is primarily concerned with the balloon-borne scientific apparatus or test package that is the basis of his mission. For collection, telemetry, recording and display of the data, and command-control of the experiment, the scientist usually relies upon the personnel and instrumentation at the test facility. This paper discusses the capabilities available at AFGL Detachment 1 for reception, collection, manipulation, recording, and display of telemetry data transmitted from the balloon-borne instrumentation.

The ground system operates either with standard, balloon-borne PCM data encoders provided by AFGL, or in special circumstances, with encoders supplied by the experimenter. Multiple displays present information in real-time from the on-board scientific apparatus. The collected data are recorded on analog and digital magnetic tapes for analysis either at the ground station, or later, at the user's home station. The ground station is configured about a Digital Equipment Corporation PDP-11/40 computer and its peripherals and EMR telemetry equipment.

2. GENERAL DESCRIPTION

The AFGL Detachment 1 balloon flight facility is located in Building 850 on Holloman Air Force Base, near Alamogordo, New Mexico. All real-time data collection and scientific display capabilities are conveniently located within a single room. Directly across the corridor is "mission control". Here the mission controller is primarily concerned with balloon launch, flight control, safety and recovery operations.

This AFGL facility has a very versatile communication system for in-flight data recording, display and uplink commands. Both Frequency Modulation (FM) and Pulse-Code Modulation (PCM) telemetry systems are available with a variety of equipment which allows the scientific user accurately to recover, display and record data from balloon-borne experiments. A block diagram of this system is shown in Figure 1. Line printers, cathode ray tubes (CRT's), analog pen recorders, nine-track digital tape units, and disks allow the user to record and/or monitor vital data received from the balloon in real-time. Based on the information presented on the display system, the scientist may decide to alter experiment operations, or to change the balloon trajectory. With the PDP-11/40 digital computer, the experimenter can manipulate the received signals so that selected data parameters can be displayed in scientific form for ease of interpretation. All recorded data can be replayed at real-time speed or more slowly, either to verify operational readiness, or in preparation for subsequent flights. For in-depth data reduction and analysis, the data recorded from the system can be made compatible with large-scale, data-reduction facilities.

The base facilities at AFGL Detachment 1, can provide commands and receive data for various missions in real-time from balloon-borne devices at operating ranges as far as 250 miles away when the balloon altitude is 50,000 ft. or higher. This coverage allows routing operational support to launches at Holloman AFB and to the various other sites in and around White Sands Missile Range (WSMR), adjacent to Holloman AFB.

A mobile facility with similar data acquisition capabilities is also available to the user who requires coverage from remote launch locations, or extended coverage for flights from Detachment 1. The mobile facility can be strategically located, with a telephone communication link to the base facilities.

Due to the flexibility of the PCM system, the bit rates, bit order, word sizes, and data content can be adapted to a wide range of formats. Nominal data rates for most applications is in the lower kilobit range. Data rates as high as 512,000 bits per second and 1600 frames per second

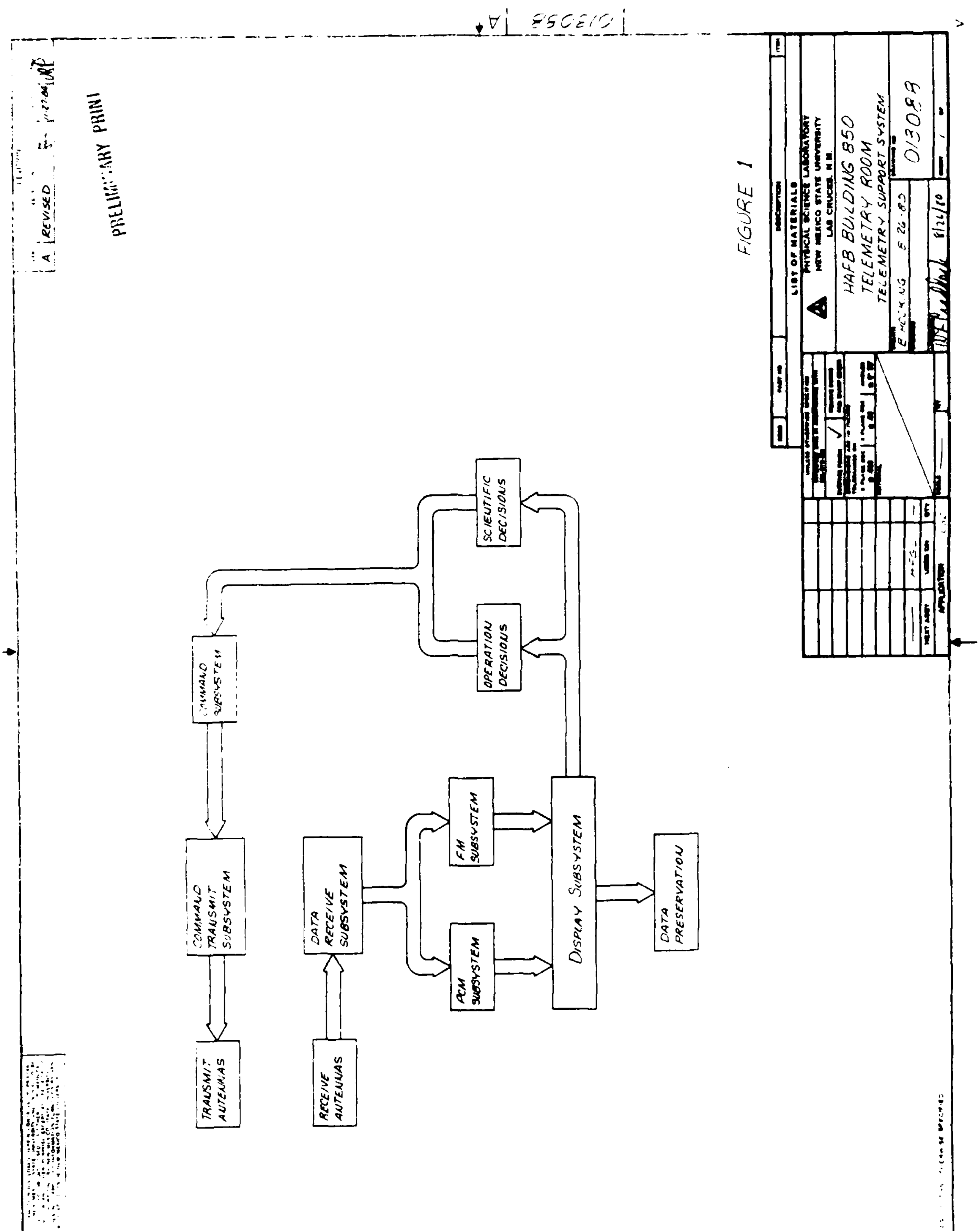


Figure 1
Telemetry Support System

have been successfully received and processed and the data displayed. Bit rates as high as 2,000,000 bits per second might possibly be used, but would be at the upper limit of the capability thus requiring higher magnetic tape speeds, etc. Standard software is available for the "standard" balloon control data set, and "special" programs can be developed for users with individual requirements of CRT displays or plots.

3. RECEIVING SUBSYSTEM

The receiving subsystem is the "front end" of the telemetry ground station. The radio frequency signals are received from the balloon-borne transmitters and are routed to the subsystem which can convert them back into meaningful data. An Andrews Corporation steerable-antenna system is used to receive these signals. A picture of the antenna is shown in Appendix A.

Signals are received during setup for launch and while the balloon is moving out of the launch area. The manually-controlled antenna can be pointed in any direction in order to optimize reception of the signals. From the antenna system the signals are routed to a multicoupler. The multicoupler accepts a single antenna input and generates multiple outputs. These outputs are presented to the Microdyne 1100 AR S-Band receivers.

Each receiver is tuned to discern the preassigned transmitter frequency from among others that may be present. With input in the S-Band frequency ranges, each receiver provides an output which can be presented to either the PCM subsystem or the FM subsystem. A functional block diagram of this system is shown in Figure 2. Arrangements are often made to use the White Sands Missile Range Transportable Telemetry Acquisition System (TTAS) which has an automatic tracking antenna system. Also, signals may be relayed to Detachment 1 from the WSMR telemetry station, J-10, via additional S-Band links.

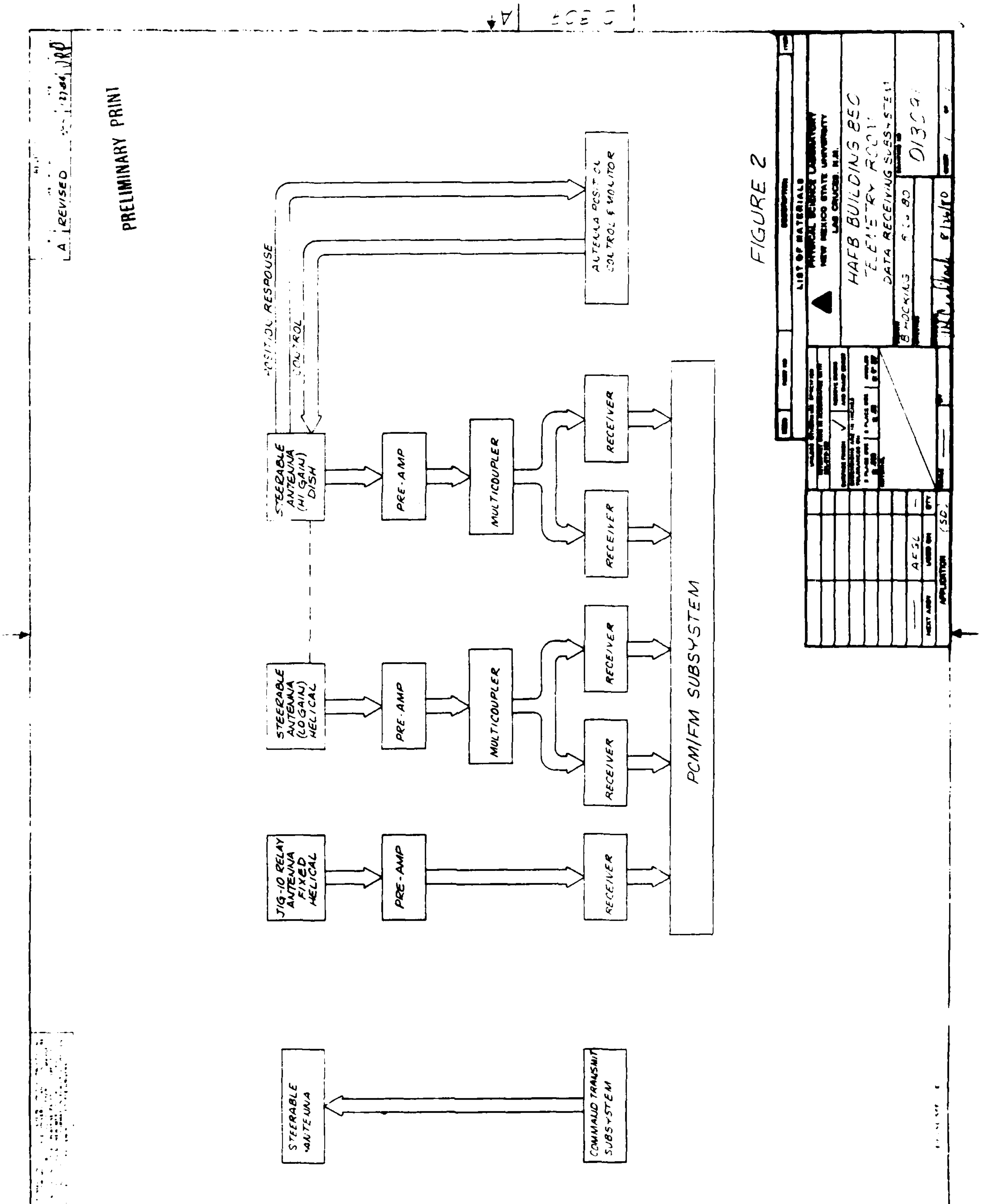


Figure 2
Data Receiving Subsystem

4. PCM TELEMETRY SUBSYSTEM

Within the telemetry system there are two distinct capabilities, PCM and FM. In general, the PCM system provides more flexibility in data encoding and transmission. The PCM subsystem is configured around the Digital Equipment Corporation (DEC) PDP-11/40 digital computer. Data flows into and out of the computer via the flexible DEC UNIBUS. A block diagram of the PCM subsystem is shown in Figure 3.

Since there are two EMR 720 Bit Synchronizers and two EMR 710 Decommutators, the PCM subsystem can process two wavetrains of data. Data is obtained from the receivers of the receiving subsystem. The information is presented to the EMR 720 Bit Synchronizers. The Bit Synchronizer accepts the PCM data in the presence of noise and other perturbations and generates reconstructed, coherent PCM data and multiple clock outputs. The EMR equipment can process all standard Inter-Range Instrumentation Group (IRIG) PCM codes, which include NRZ-L, NRZ-M, NRZ-S, Biø-L, Biø-S, Biø-M, RZ, DM-M and DM-S. The system offers a high level of performance over the range of 1 bps to 2,000,000 bps. It can handle any of four different signal inputs. Currently, these include the five S-Band receivers and a PCM Simulator. The EMR 720/710 can be either manually programmed for the particular PCM format or controlled by the PDP-11/40. The multiple inputs allow rapid selection of the different signal sources so that data reception and system testing can be optimized.

The NRZ-L PCM data and clock outputs of the EMR 720 Bit Synchronizer are routed to an EMR 710 Decommutator (see Figure 4) which performs frame synchronization and serial-to-parallel conversion, and provides a parallel data multiplex output with synchronization information. Any frame-synchronization pattern between four and 33 bits, with frame lengths of up to 512 words and bit rates as high as 2,000,000 bps, can be accommodated. One EMR 710 Decommutator has a variable word length card which allows varying word lengths to be used throughout the wavetrain. The 710 parallel output and synchronization information is presented to an EMR 713 Programmable Word Selector and the Buffer Data Channel.

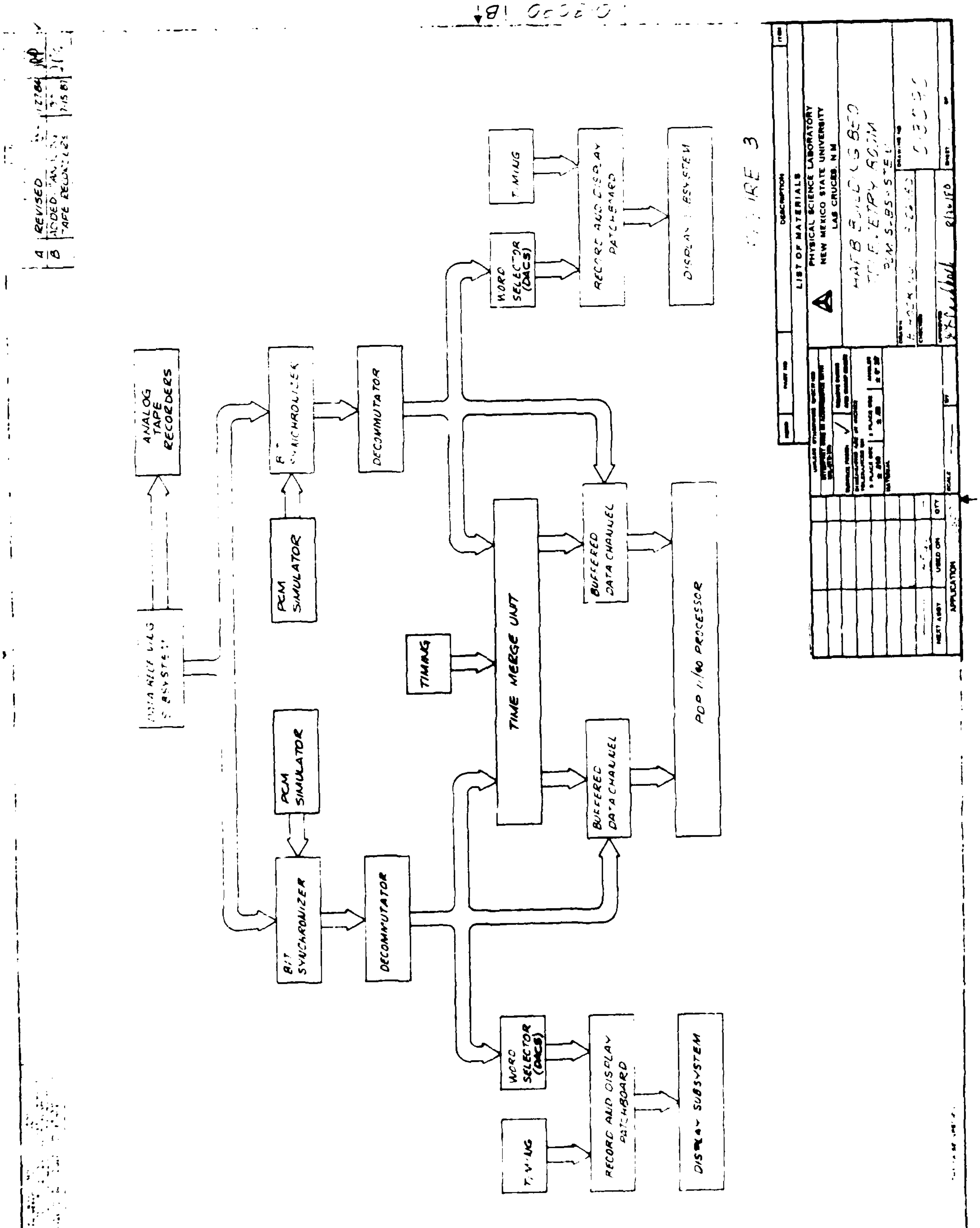


Figure 3

PCM Subsystem

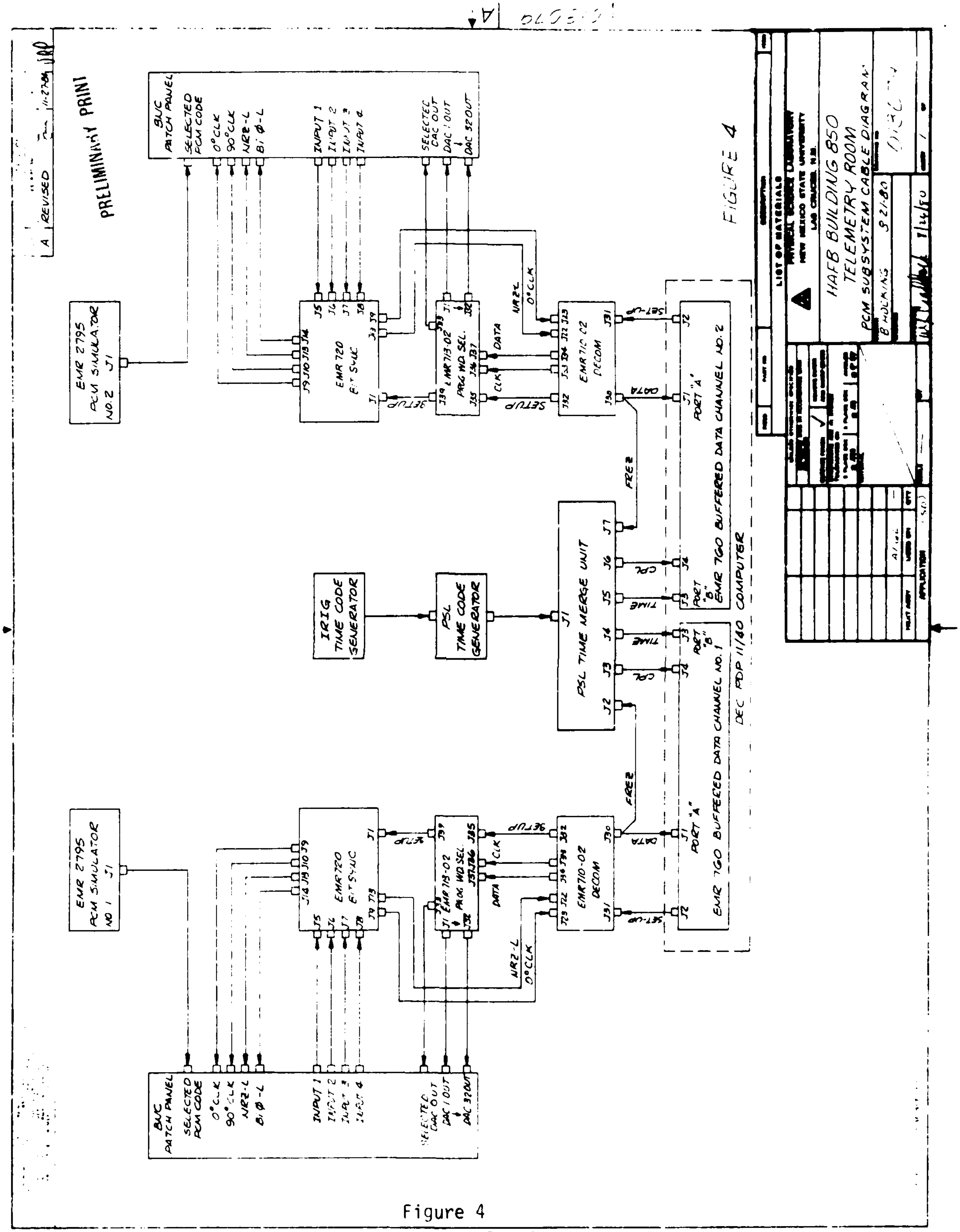


Figure 4

PCM Subsystem Cable Diagram

The EMR 713 Word Selector converts selected words from the received PCM data to analog form. Each EMR 713 has 32, 10 bit digital to analog converters. Both main-frame data words as well as subframe-data words can be selected. Output analog data words are represented by a dc voltage of 0 to 10 volts. The analog channels are updated at the frame and subframe rate of the incoming data. Each of the 32 analog output data channels is routed to a display patchboard for assignment to analog display devices selected by the scientific user or instrumentation manager.

The EMR 760 Buffered Data Channels under program control and initiation, will transfer the parallel data words from the decommutators into program-selected segments of the PDP-11/40 processor memory. This transfer takes place under Direct Memory Access (DMA) and interrupt control, which minimizes attention required by the program and maximizes throughput rates. A realistic maximum transfer rate of about 400,000 16-bit words per second can be transferred to the processor memory by this device. Communication between the 760 and the PDP-11/40 is through the PDP 56-line UNIBUS. The transfer rate is limited by the UNIBUS and the operating system, not the EMR 760. At this point, selected PCM data received from the balloon-borne experiment are presented in real-time to a digital program being executed within the PDP-11/40 processor. The data are available for display or manipulation according to algorithms defined by the scientific user. Output displays and permanent recordings are also selected according to the data collection requirements.

For pre-mission testing and system evaluation, each decommutator has an EMR 2795 PCM Simulator which generates signals like those to be received from the balloon-borne telemetry package. The 2795 formats can be generated with up to 599 words in the mainframe and up to 599 words in the subcommutated frame, and with word lengths from one to 33 bits. Serial PCM signal outputs can be in any one of eight codes which include NRZ-L, NRZ-M, NRZ-S, RZ, Biø-L, Biø-M, Biø-S, and DM-S at bit rates from 1 bps to 2,000,000 bps. Magnetic tape recordings of previous flights of the same payload, or previous ground test are also useful in checking system setup and software modifications. For Frequency Modulated (FM) telemetry systems there are available 32FM TRI-COM Model 401-95 discriminators.

Also available is an EMR 4140 Tunable FM Discriminator. Two views of the telemetry station are shown in Appendix A. One picture shows the telemetry subsystem, receivers, and main patch panel. The other picture shows the analog chart recorders and tape recorders.

5. PDP-11/40 PROCESSOR

The center of the PCM processing system is a PDP-11/40 Computer. This computer accepts the PCM and time inputs, processes selected data according to pre-defined algorithms, and outputs the results to displays or permanent storage devices. The digital real-time program which resides in the processor controls this data flow and performs the data manipulations. A block diagram of the PDP-11/40 processor subsystem is shown in Figure 5.

The PDP-11/40 computer is a 16 bit, general purpose, parallel logic, microprogrammed computer using single-and double-operated instructions and "2's complement" arithmetic. The system contains a multiple-word instruction processor which directly addresses up to 256K bytes of memory. All communications among the system components (including processor, memory, and peripherals) are performed on a single high-speed bus, the UNIBUS.

The central processor unit (CPU) is a KD11-A which decodes the instructions; accepts, modifies and outputs data; performs arithmetic operations; and controls allocation of the UNIBUS among external devices. The processor recognizes four levels of interrupts with each major level containing sublevels. The priority level of the processor is itself programmable, allowing a running program to select the priority level of permissible interrupts. Additional speed and power are added to the interrupt structure through the use of the fully vectored interrupt scheme.

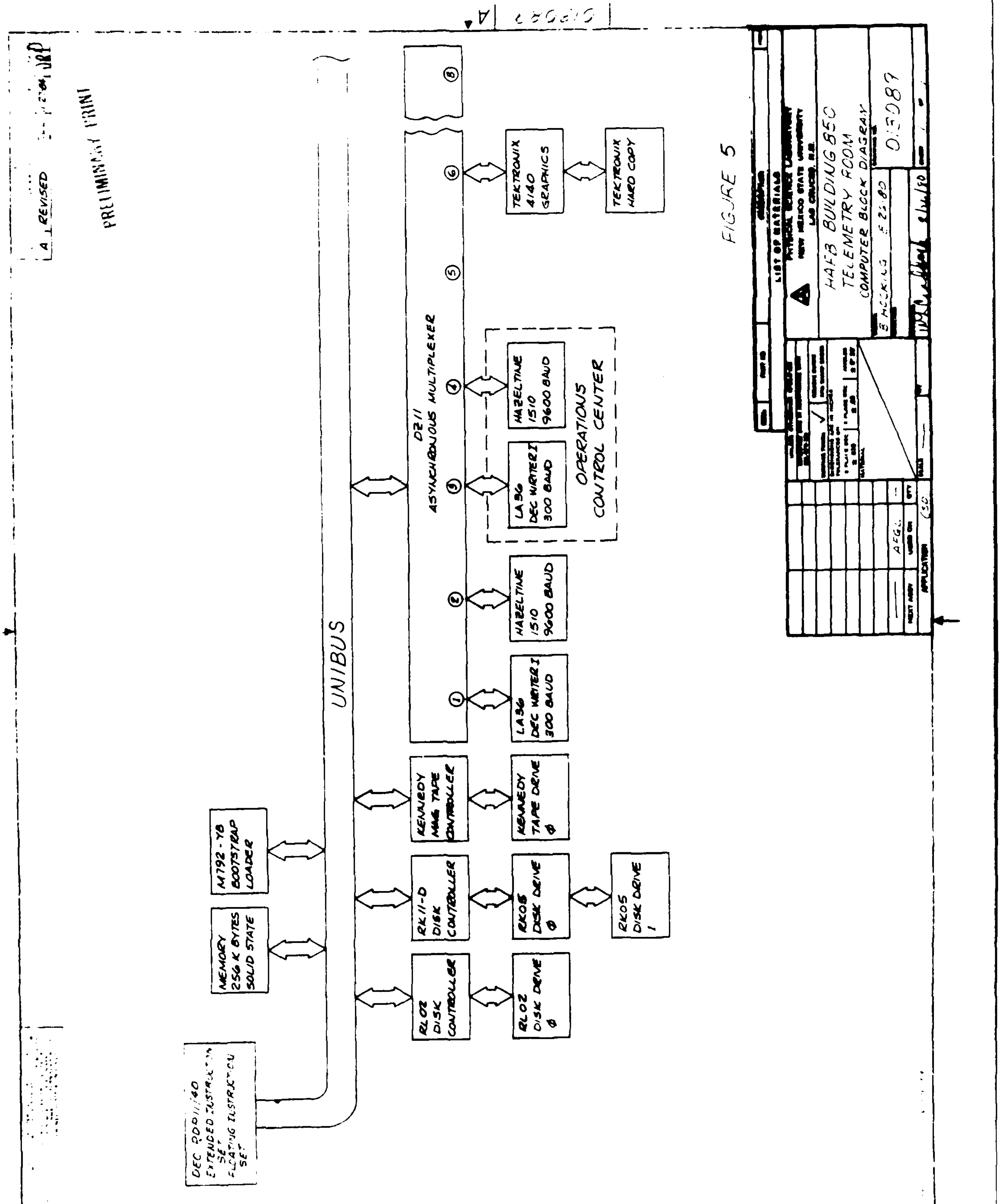


Figure 5
Computer Block Diagram

Contained within the CPU is the Extended Instruction Set option (EIS) which provides the capability of performing hardwired fixed-point arithmetic. Also within the CPU, is the Floating Point Unit option which allows the execution of four special instructions for floating point addition, subtraction, multiplication and division. Together, the EIS and Floating Point capabilities allow significant execution time and program implementation improvements over the comparable software routines. In effect, complex mathematical algorithms can be performed in less time, thus enabling the processor to handle larger user-task routines.

The memory of the processor is on two cards with a total of 256K bytes of solid-state memory.

6. PDP-11 PERIPHERALS

A number of peripherals are attached to the PDP-11/40 to optimize program development, user output display, and system control. A DZ-11 card is used to connect the terminal units with the PDP-11/40. The DZ-11 is an asychronous multiplexer for up to eight RS-232 devices. These devices consist of CRT terminals and printers. A disk drive and a magnetic tape drive are also connected using their own interface cards. Several hardcopy devices have been used within the system; an LA30, 2 each LA36 DECwriters and a Tektronics Model 4014 Graphics terminal with a hardcopy unit.

The LA30 DECwriter is a dot-matrix impact printer and keyboard capable of printing a set of 64 ASCII characters at a speed of up to 30 characters/second on a sprocket feed 9-7/8-inch wide continuous form. Each line is 80 character positions in length with a spacing of 10 characters per inch, and a vertical spacing of six lines per inch. This unit is not presently connected to the system.

The LA36 DECwriter II hardcopy device is located in the telemetry/display room where information for the scientific user can be displayed. An LA36 DECwriter II is a medium-sized, interactive data-communication terminal with a standard ASCII-coded keyboard (consisting of alpha-numeric

characters and nonprinting characters) and prints at a horizontal spacing of 10 characters per inch with a maximum of 132 characters per line, and a vertical spacing of 6 lines per inch. The printer is capable of handling continuous multipart- and multiform-line printer paper from 3 to 14-7/8 inches wide. The print rate is selectable from 10, 15 or 30 characters per second. In addition to being available as a scientific data output device, it is also used as the primary program setup and initiation input device by the operator.

For software program development and storage, there are two RK05's and a RL02 disk drive. At present only the RL02 is being used because the RL02 has more capability. The RL02 disk drive is a self contained random access, mass storage device which uses a high-density single-disk, 40 sector cartridge as its storage medium. Two movable heads can record or read up to 1024 data tracks which can store up to 10.4 mega-bytes of data.

Two CRT Hazeltine 1510 terminal units are incorporated into the system to display dynamic data to the viewer. One CRT can be located in the operation control room where the mission controller can access special routines within the processor. For example, utilizing the two-task program execution capability of the processor, the mission controller can select display pages. These display pages show information such as ballast being dropped, helium being valved, altitude, pressure, temperature, and time left on automatic timer.

The second CRT is located in the telemetry/display room and is available for display of a page listing user-selected parameters. The data is dynamic information updated at the sampled frame rate. The CRT display will up date at a slower rate depending on the time required by other concurrent task which the computer is performing. Battery voltages and currents, positions, etc. can be displayed in a fixed format on the CRT with engineering unit conversion. Additional assists to the user are available by allowing the user to define critical parameter-monitor algorithms, for example, allowing the processor to automatically monitor battery voltages, and providing output alerts to the operator via the CRT if they exceed predefined values. These

algorithms can be as versatile as needed by the specific user. The specific requirements must be made known to the programmer and funding for this support must be available with enough lead time for the program to be written or modified.

The two CRT's used in the system are Hazeltine 1510's. The 1510 has a video terminal as well as a keyboard for data entry. The keyboard is the same as a standard typewriter plus a keypad which together include the upper- and lower-case ASCII character set. The video screen will accommodate 24 lines of information with 80 characters per line with both foreground and background display modes. Also available to the user is full cursor control using direct cursor addressing plus individual cursor control keys.

Two DEC VT-102 terminals have also been used with the system. The VT-102 has all the features of the Hazeltine 1510 terminal plus a selectable 14 lines x 132 characters per line display. The keyboard is an 83-key detachable unit.

For digital data logging a magnetic tape unit is available. Raw input data or the intermediate and/or final results of calculation can be recorded on digital tape which is compatible with most user computer facilities. A Kennedy 9300 Digital Magnetic Tape System is used for recording this data from the processor. The Kennedy 9300 accommodates reel sizes up to 10-1/2 inches in diameter with computer-standard hubs. The tape medium is 1/2 inch wide by 1.5 mil thick mylar, standard computer tape. Recording densities are selectable from either 800 or 1600 bits per inch using either even or odd parity.

7. SOFTWARE

The PDP-11/40 processor can process, display and record telemetry data as received from the balloon. This is achieved by special real-time software which resides in, and is executed by, the computer. Within the software are contained the algorithms necessary to perform all required tasks, such

as data conversion, data recording, operator display, real-time logging to the hard copy devices, and real-time computations.

In order to make the system as flexible as possible, the software has been structured as a collection of closely related but independent modules required to perform the desired tasks. Many functions such as Input/Output handlers have been coded at the assembly level and integrated into the RSX-11-M-V4 operating system. Other more "mission specific" functions are coded in PASCAL to allow easy modification as requirements dictate.

More flexibility is also realized by utilizing a priority structure whereby the more time-critical functions are performed at the expense of the less critical functions such as hardcopy logging. This keeps the slower I/O devices from slowing down the rest of the system.

Real-time and support programs are the two types of programs employed at the facility. The support programs are those which are structured to do various special purpose tasks such as system checkout, maintenance, calibration, etc.

The primary program is the real-time program. Execution in real-time implies that the dimension of time must be incorporated into the execution of the instruction sets. For the telemetry system, this will be accomplished by subdividing each second into equal intervals. Within each interval the operational program set of instructions will be executed. When completed, the processor will "idle" until the start of the next interval. This process is repeated for each interval. If there are more tasks to be executed in any given cycle than there is time to do it, those functions (or tasks) with the lowest priority will be deferred until a later cycle.

Real-time data processing is highly dependent upon the quantity of input data and its input rate, and the amount of processing required. The data received at the computer is a composite of scientific information as well as balloon status data, which is further merged with time-of-day.

The continuous calculation and display of balloon altitude from pressure transducer is an example of a typical real-time computation used by the scientist as well as the operational personnel. The altitude computation involves several stages. Calibrations of the balloon-borne pressure transducers are entered into the computer to establish the relationship between the transducer voltage and the actual pressure. During the balloon flight (in real-time), the transducer voltage data point is received and converted to pressure using the pre-flight data base. With a pressure value, the "altitude" can then be quickly calculated. Further calculations can be made using the altitude information to yield ascent and descent rates. These parameters are then dynamically displayed.

The computer and associated terminals are shown in the last picture in Appendix A.

8. TIMING

For all experiments or missions time must be recorded for later data reduction and correlation. A station WWV receiver is used to synchronize the time decoders within the system to a standard source.

The Datametrics SP-100 Time Code Generator is synchronized with the WWV time. This unit generates timing in Inter-Range Instrumentation Group (IRIG) formats for recording on the analog recorder and use on the strip-chart recorders.

A second time code reader, a PSL Model 10938 Time Code Reader/Generator, is also incorporated into the system. The time code reader will accept the output of the Datametrics generator, or the recorded time on the analog tape, in order to generate parallel time for the PCM time merging interface. In the event that no other time source is available, the generator portion of the unit can provide this output. Additionally, time can be routed to the analog devices if required. The Model 10938 is capable of decoding or generating any of 13 different line-level, carrier-modulated standard IRIG/NASA time codes.

The PCM time merging interface causes the EMR 760 Buffered Data Channel to switch its data entry port at a selected time and rapidly transfer three time words into this alternate port. Upon completion of the time transfer, the EMR 760 port is allowed to revert to the true data port. The "FREEZE" timing pulse from the EMR 760 controls this operation.

9. DATA DISPLAY SUBSYSTEM

In any real-time operation the flight control personnel as well as the scientific user must be able to monitor received data visually in real-time. Based upon the information received, the cognizant personnel can make judgmental decisions for continued experiment operations.

Information can be displayed in both digital and analog form. For the display where trends as a function of time are desirable, analog strip-chart records can be used. Five Brush recorders, models 260 and 481 (6 channel and 8 channel, respectively), provide 36 channels of analog data displays. Each recorder can be continuously annotated with time-of-day (TOD) information with IRIG time codes for interval correlation for multiple data comparison. The recorders can be run at various speeds to optimize the details of the displayed parameters.

Where only information regarding the instantaneous state of a parameter with respect to maximum or minimum values is desired, the analog meter bank can be used. This display device contains 20 analog voltage meters, each accessible from the display and record patchboard.

Standard "housekeeping" information from the PCM data received from the balloon is processed by the computer and is displayed in such forms as altitudes, pressures and temperatures. This is accomplished through algorithms expressing the relationship of the desired parameter to the corresponding sample voltage measurements sensed by instruments on the balloon. The experimenter can submit to the telemetry programmer algorithms to convert selected sensor data telemetry "words" to engineering units for real-time display during the flight. The

programmers must be notified of the requirements and funding provided with adequate lead time.

These information outputs can be assigned to various digital display devices dependent upon the type of data.

The capabilities of the hardcopy devices (LA30 and LA36) are explained in earlier sections. Each data set or event to be hardcopied can be time tagged for correlation with other data. Typically, this would be information significant to the operational or experimental decision-making processes so that the resulting time history can be reviewed during post-operation analysis.

10. MAGNETIC DATA RECORDING

The end product of most experiments is the data which is collected during the mission. This data is generally used for further in-depth analysis at the experimenter's laboratory. It is therefore important that the user be able to acquire data in a medium compatible with whatever reduction facility may be used. Digital and analog recording are the two primary forms of magnetic data recording used.

The digital recordings are made via the PDP-11/40 processor subsystem. Whatever is recorded on the nine-track output tape (described in the PDP-11/40 Processor Subsystem Section 6) is completely selectable by the data requestor. All raw data, or only selected data, may be recorded, always with time information. If specific formats are required they can be provided. The digital data tapes of the PCM data are usually made from the analog data tapes after the mission, so that the experimenter can select segments of interest for digital recording and subsequent computer processing. However, if the digital tape is made in real-time then that task is assigned highest priority and any other task such as CRT data displays may be updated at a much slower rate, impairing their usefulness.

The raw receiver video output of information being received from a balloon-borne experiment is recorded by either a Sangamo SABRE IV or one of two SABRE III analog magnetic tape recorders see Figure 3. These are 1/2 inch, seven-channel devices, capable of recording PCM high data-rate signals as well as FM data. Playback features allow the replaying of this data for subsequent digitizing or special display.

11. RECOMMENDATIONS

The front-end telemetry equipment at Holloman is adequate for the foreseeable future with the exception of the need to purchase two or three variable word length cards for the EMR 710 PCM Decommutators.

The area that needs considerable improvement is the computer sub-system. The trend for the past two or three years has been toward more sophisticated payloads with more complex telemetry systems and an increasing need to provide the experiment personnel with more engineering unit converted displays, graphics, etc. The balloon control telemetry data display is also evolving, though at a slower rate. The net effect is that the existing PDP-11/40 computer has been incapable of handling all the requirements in recent months. During 1984 a PDP-11/34 was borrowed from PSL in order to support "ABLE" and "GAMMA RAY" missions.

The present computer has already been expanded to the maximum memory size possible with an 11/40. However the memory is inadequate. And although the machine has multi-task capability, the speed of throughpat, even if memory were adequate, would result in slower than desirable updating of screen data if many tasks were performed simultaneously. Compatibility with Hanscom equipment and present software should be maintained if possible.

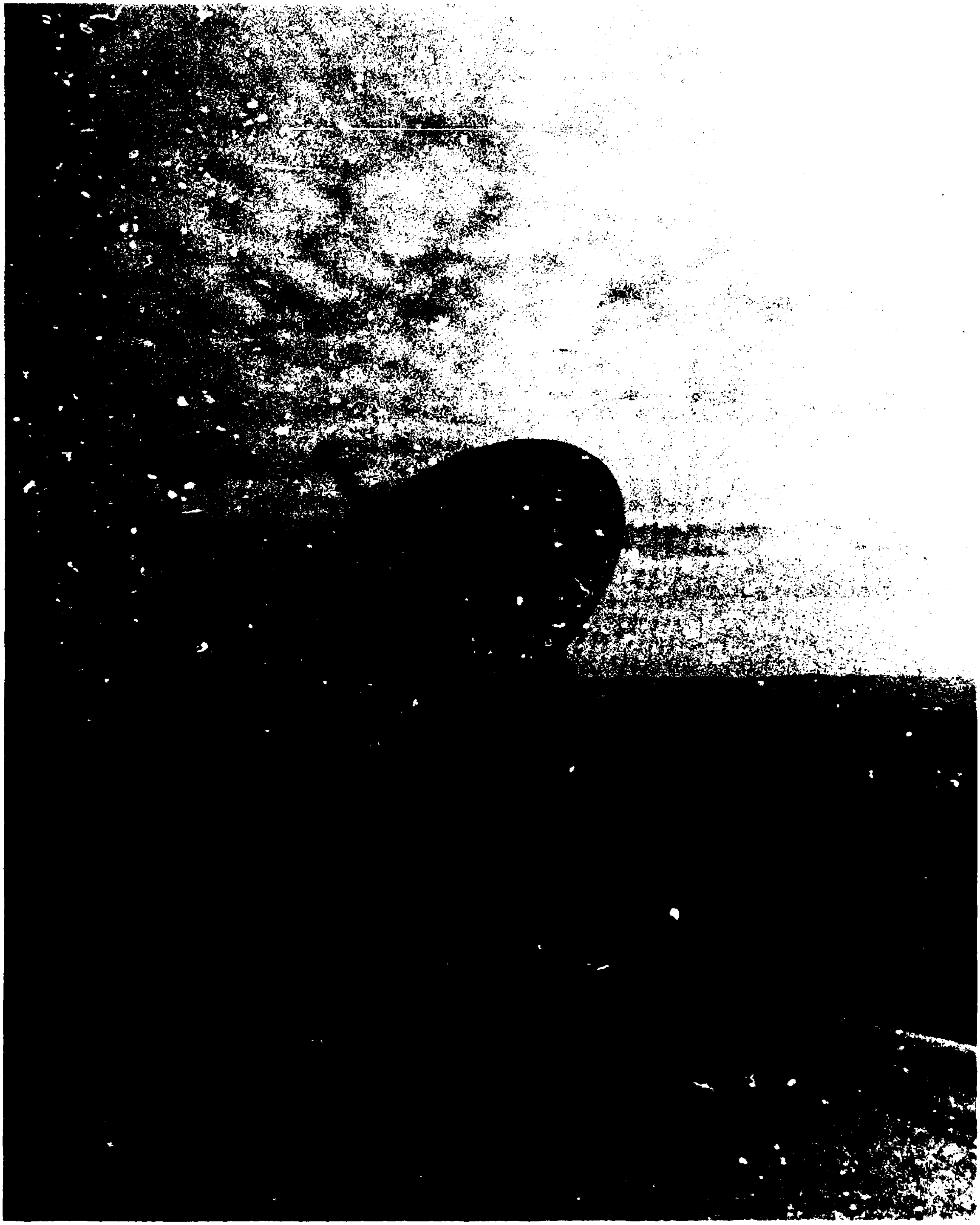
Therefore it is recommended that one of the following be done:

1. Replace the present system with a VAX 11-750, cost $250,000.
2. Replace the present system with a MINI-VAX, cost $125,000.
3. Modify the PDP-11/40 with a microverter 73, cost $14,000.

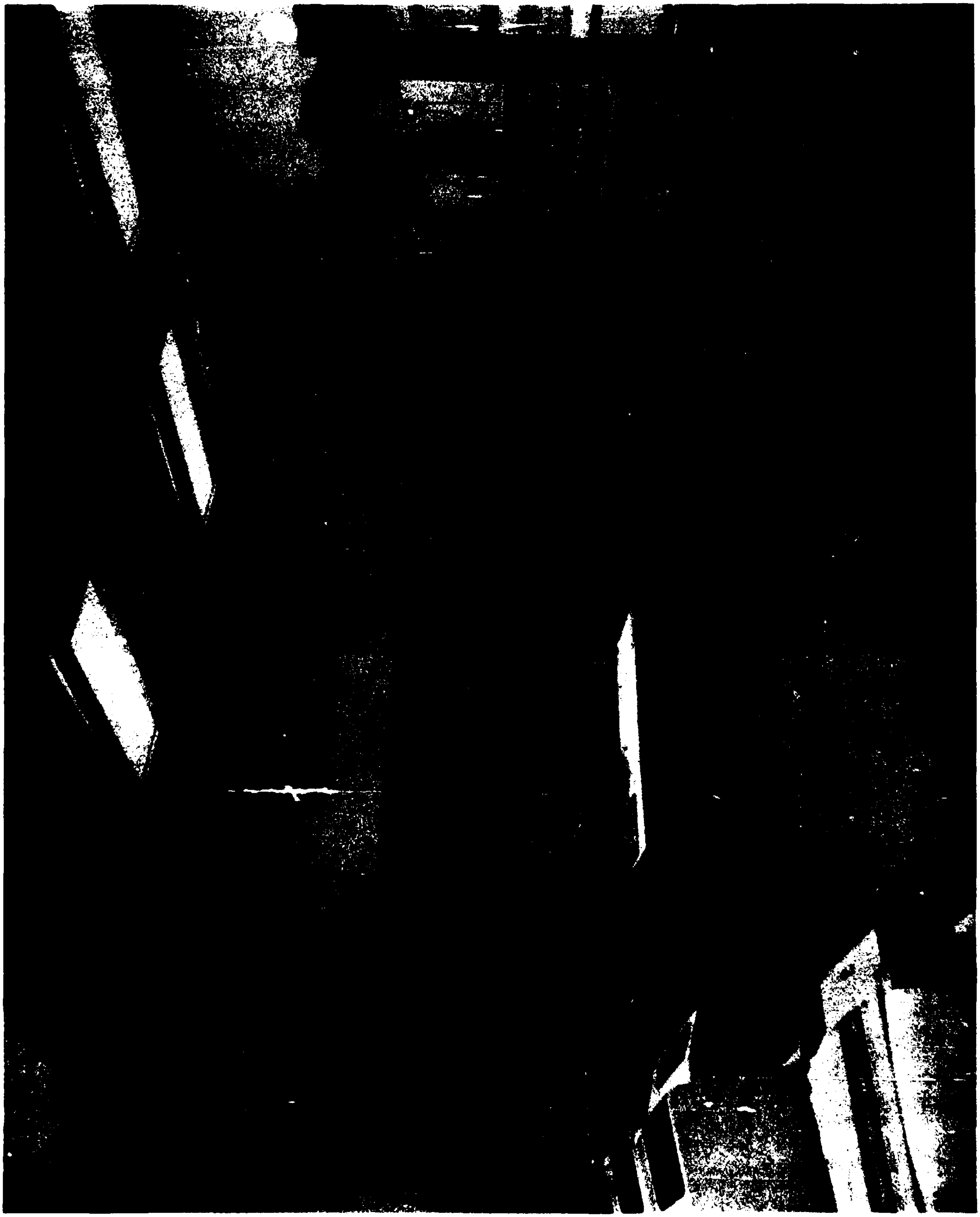
We do not have any experience with the Microverter-73. If it will perform as advertised, it will meet the needs for the immediate future. The more expensive solutions recommended above have greater capabilities and will satisfy the needs further into the future.

APPENDIX A

Photographs



S-Band Antenna



Telemetry Station

Analog Chart and Tape Recorders

Computer Subsystem